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Title: Convergent, Compressible Richtmyer-Meshkov Experiment - zero order hydrodynamics

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# Convergent, Compressible Richtmyer-Meshkov Experiment-Zero Order Hydrodynamics

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Cylindrical experiments were performed on the OMEGA laser at the University of Rochester to study unstable interfaces in single and double shells. For single shells a marker layer of more opaque and higher density material is placed between foam and an outside ablator. The marker is either smooth or with a well defined surface roughness. For double shells an inner cylinder is placed along the outer cylinder axis. The outer cylinder is irradiated directly with 50 laser beams which produces a strong shock (mach# 5-15) that passes through the unstable marker interface creating a Richtmyer-Meshkov (RM) instability. For double shells this shock bounces off the inner cylinder back to the incoming marker layer causing it to decelerate. We present comparisons of the measured smooth marker layer hydrodynamics with computer simulations using both Lagrangian and Eulerian codes.

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# Convergent, compressible Rictmeyer-Meshkov Experiments-Zero Order Hydrodynamics

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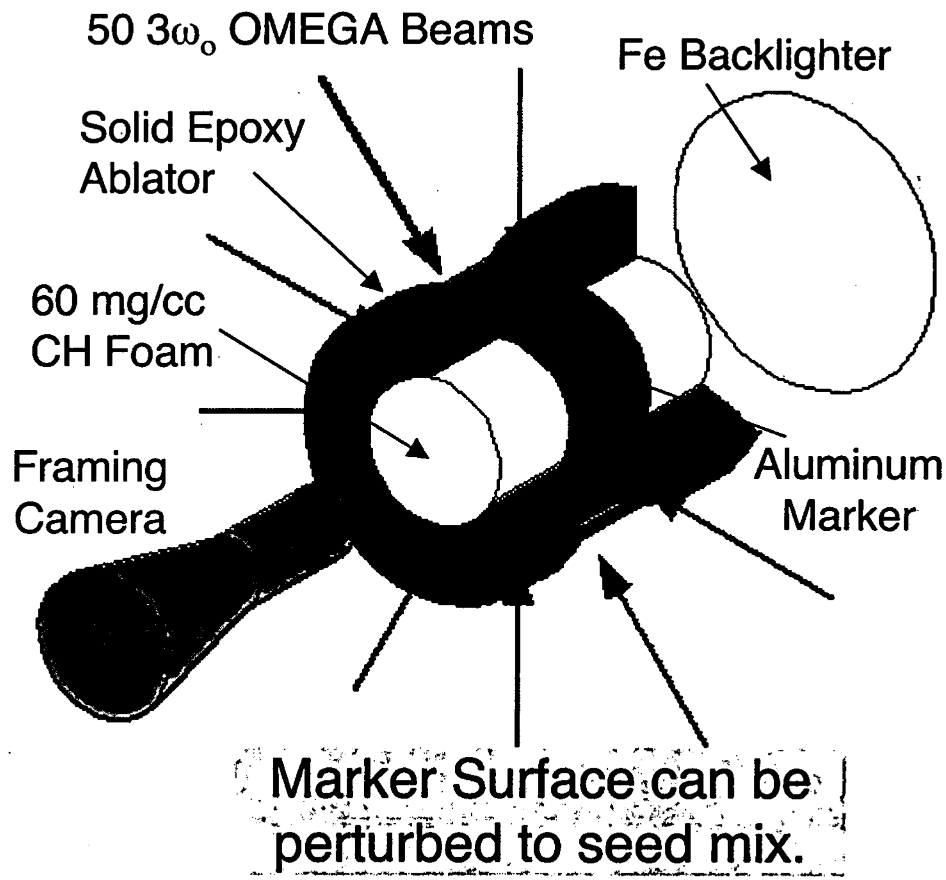
# Mix From a Heavier Shock-Driven Marker Layer Imploding into a Light Foam is Measured.

- Direct laser irradiation launches a shock that implodes cylinder.
- Both Epoxy/Al and Al/Foam interfaces are hydrodynamically unstable.
- Backlit with Fe @ 6.7 keV.
- Measure the radial extent of Al into adjacent materials.
- 1D experiment with Post-shock Mach number ≈ 5, convergence ≈ 4.3, Pressure > 45 Mbars, Reynolds Number ~ $10^6$

## Experimental Set-Up

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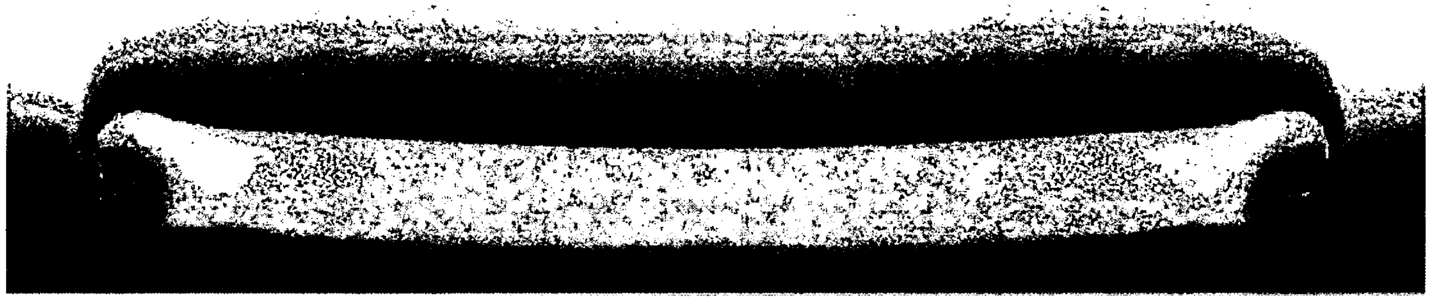
## Methodology of RAGE simulations for CYLMIX experiments

RAGE does not currently have a laser ray trace package for general use

- For these simulations laser energy is deposited some depth into the cylinder surface as an internal energy source.
- A number of 1-D simulations were performed to determine the proper depth to reproduce the stagnation time of the experiment
- The same technique using the appropriate energy reproduces the stagnation time for both the gold and dichlorostyrene marker layers in R-Z and R-$\theta$ geometry
- For smooth surface simulations one group (Grey) diffusion radiation was used
- For rough surface calculations radiation transport was turned off so that the calculations would run in a reasonable amount of time. Simulations with radiation on produced similar radiographic results
- Simulations included thermal conduction and Sesame equation-of-state and opacities
- LTE was assumed

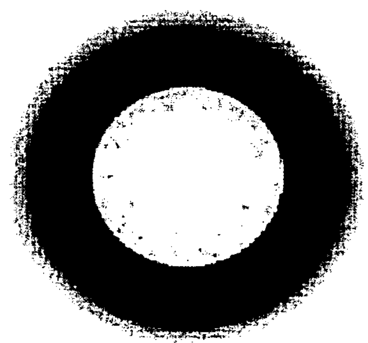
# Au marker layers because of there high opacity showed very large increases in thickness due to bowing and end effects

Au marker at 4.7 ns showing bowing and end curls



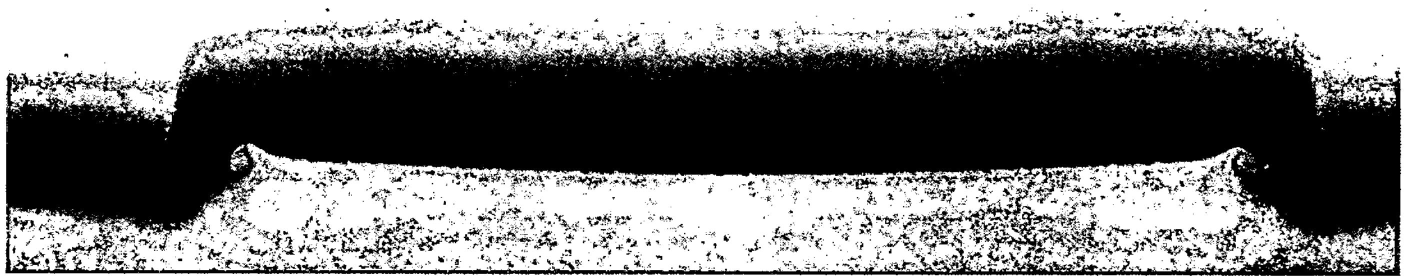
A 1D radiographic image would have a thickness of about 5 microns. Because of end effects and bowing this 2D image has a thickness of 50 microns

Radiographic image at 4.7 ns



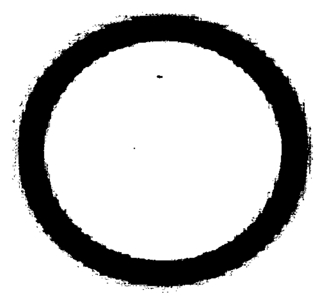
# Calculations of Al marker layers showed almost no effects from the ends or of bowing

4.7 ns

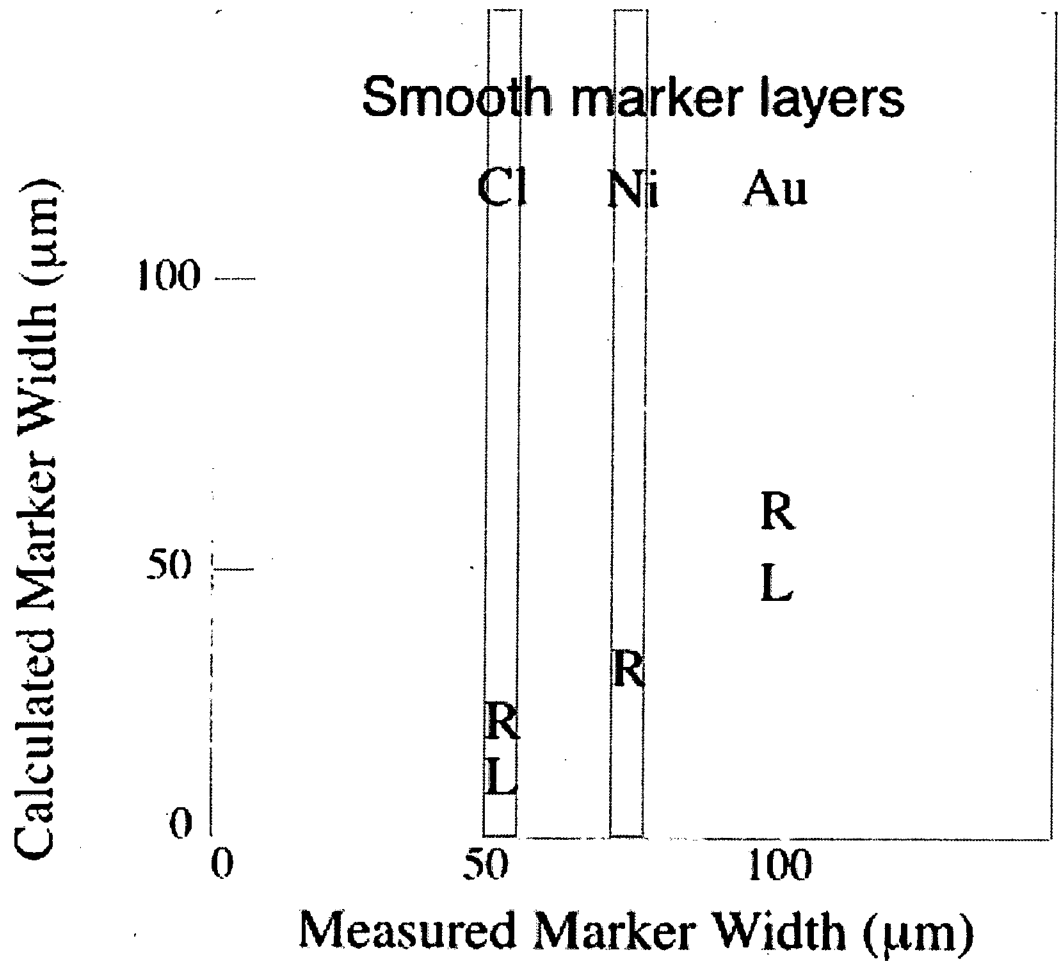


Iron Backligter Radiographic Image

The calculated 2D image of the smooth Al marker at is within 10% of what one would expect from a 1D simulation



# Our codes underpredict the marker width



# Summary

- Have done LASNEX and AMR simulations for smooth marker layers

- Simulations suggest that "end effects" will greatly increase the marker width in our smooth marker layer experiments.

- Experimental measurements suggest that our calculations underpredict the effects at the marker ends.

- Simulations indicate that the lower opacity and smaller end effects of an Al marker layer should allow us to measure a mix width for a variety of surfaces.

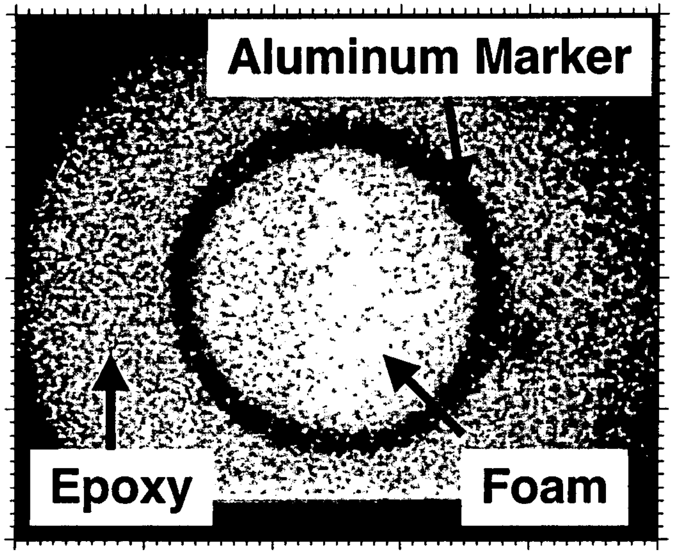
## Methodology of LASNEX simulations for CLYMIX experiments

LASNEX simulations were done totally integrated, but with smooth surfaces
Calculations included:

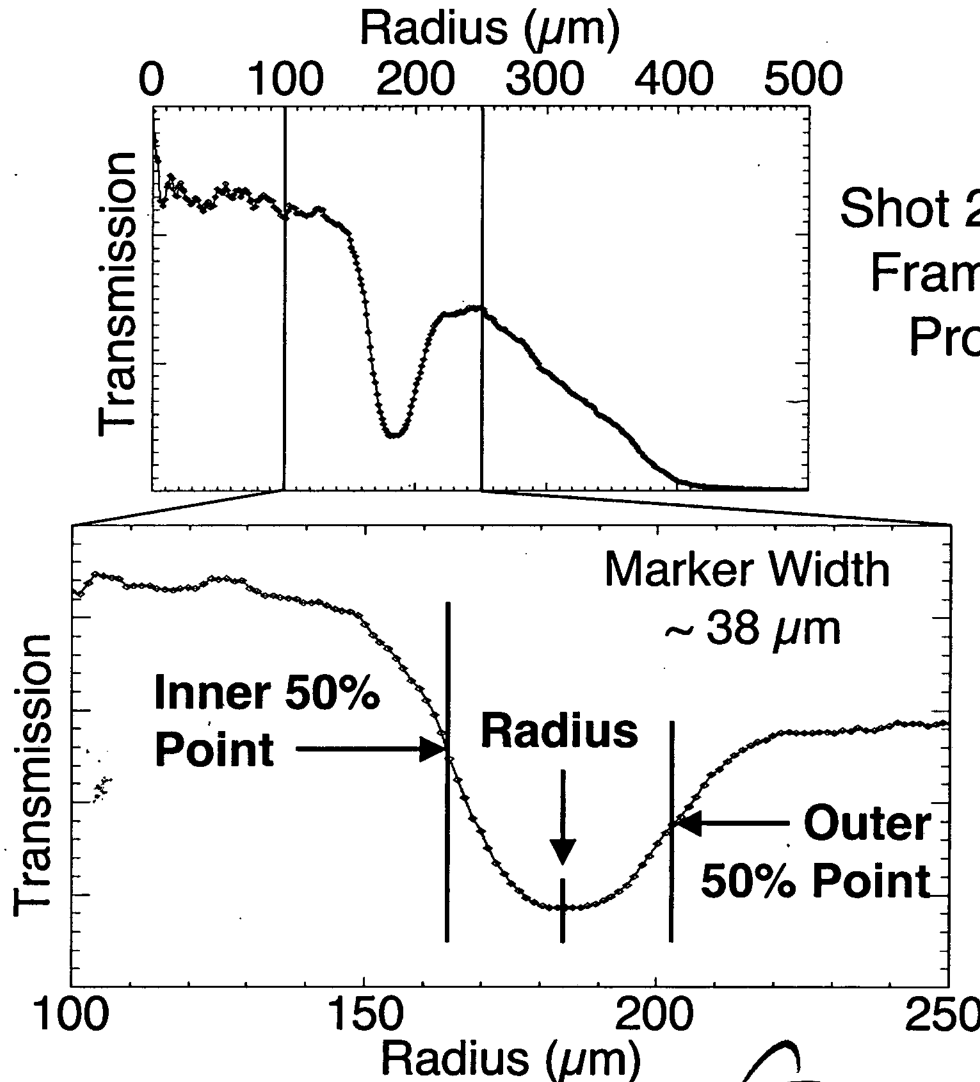
- Three-dimensional laser raytrace
- Multigroup diffusion radiation transport
- Local Thermodynamic Equilibrium (LTE)
- Sesame equation-of-state and opacities
- Thermal conduction
- Bremstrahlung laser absorption

# Minimum Transmission Determines Marker Radius; 50% Points Designate Marker Width.

Shot 26714 Frame 2b



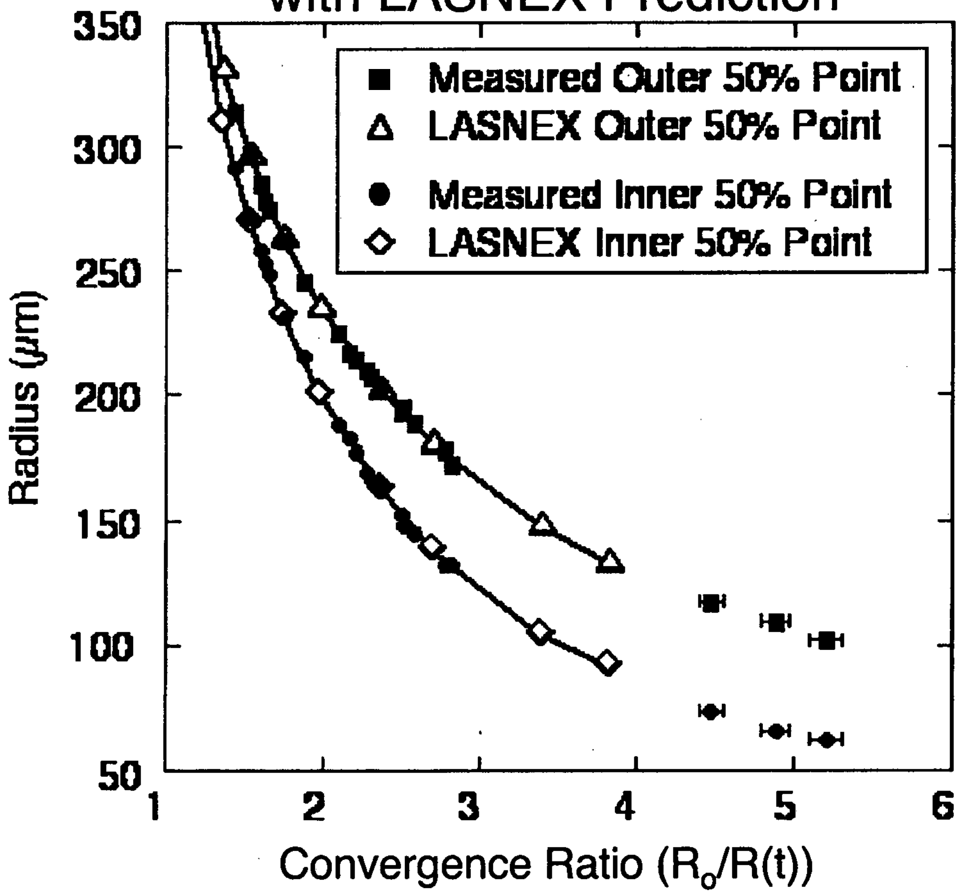

- Profiles are azimuthal averages over selected angles.




Shot 26714 Frame 2b Profile

# LASNEX Accurately Models the Zero-Order Hydrodynamics of Initially Smooth Markers.

Composite of 6 Smooth Shots with LASNEX Prediction




- Convergence Ratio = $R_o/R(t)$, where R(t) is determined from measurements.
- Experimental data is of Smooth targets, i.e. no intentionally seeded mix.
- Simulations were conducted with as-shot parameters.
- Inner and Outer 50% points extracted from LASNEX's radiographic predictions.

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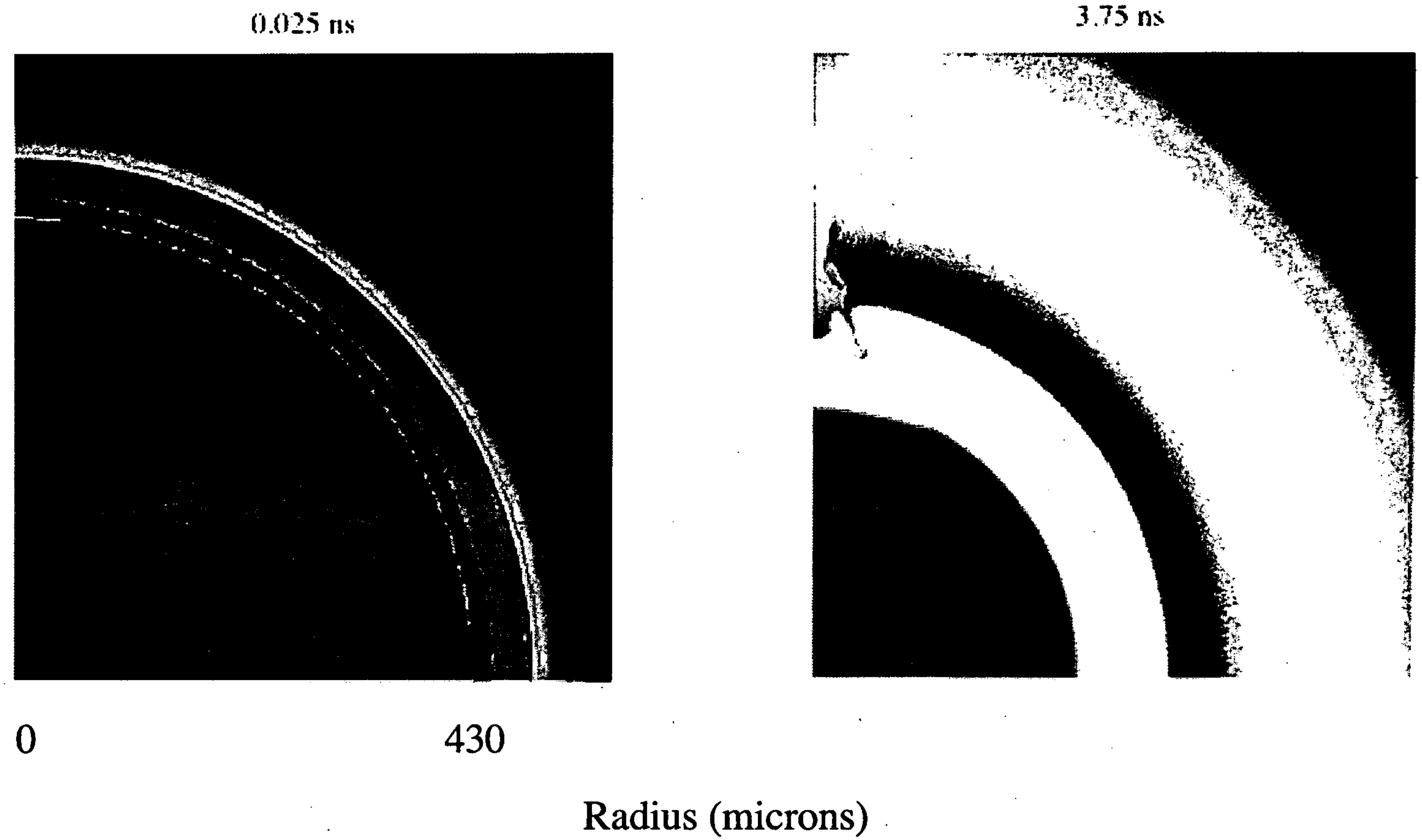
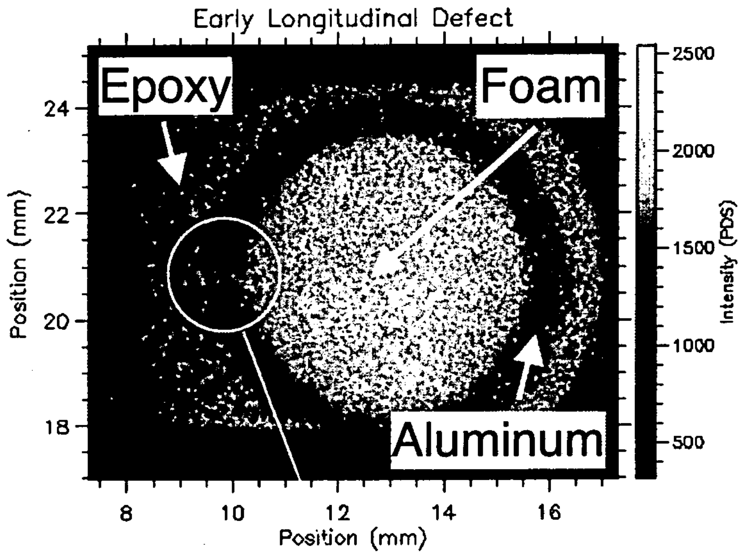
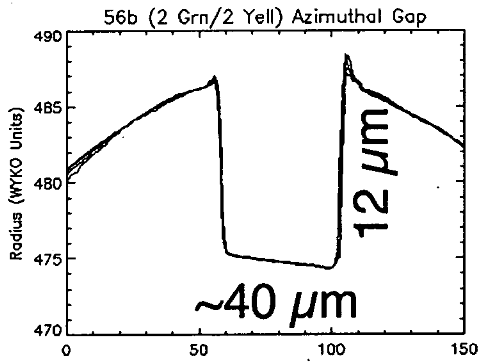
# Density evolution of the longitudinal defect shot in July



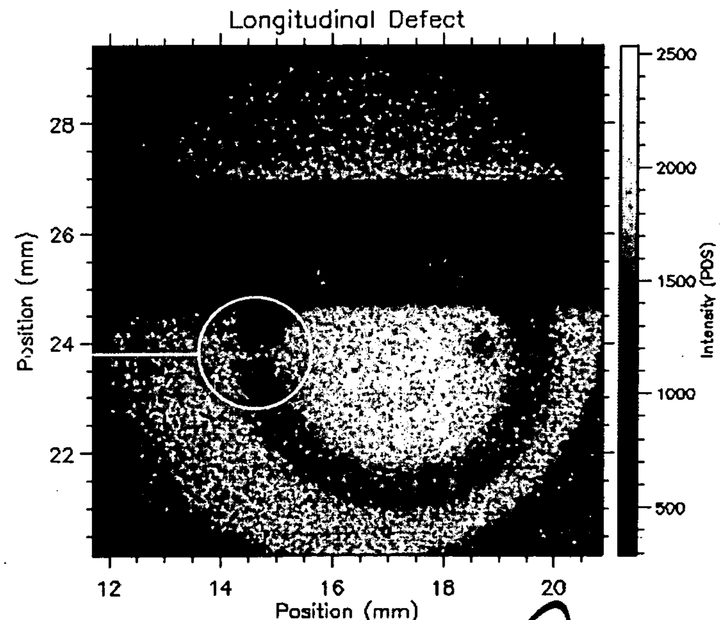
# 40-$\mu$m Longitudinal Defect Remained Visibly Open, Even at Late Times (~ 5.0 ns).



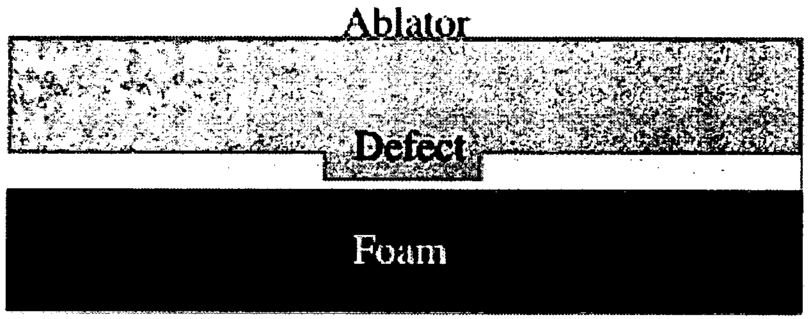




- Marker Band
  - 500 $\mu$m Long
  - 16 $\mu$m Thick
- Axial Gap
  - 40 $\mu$m Wide
  - 12 $\mu$m Deep

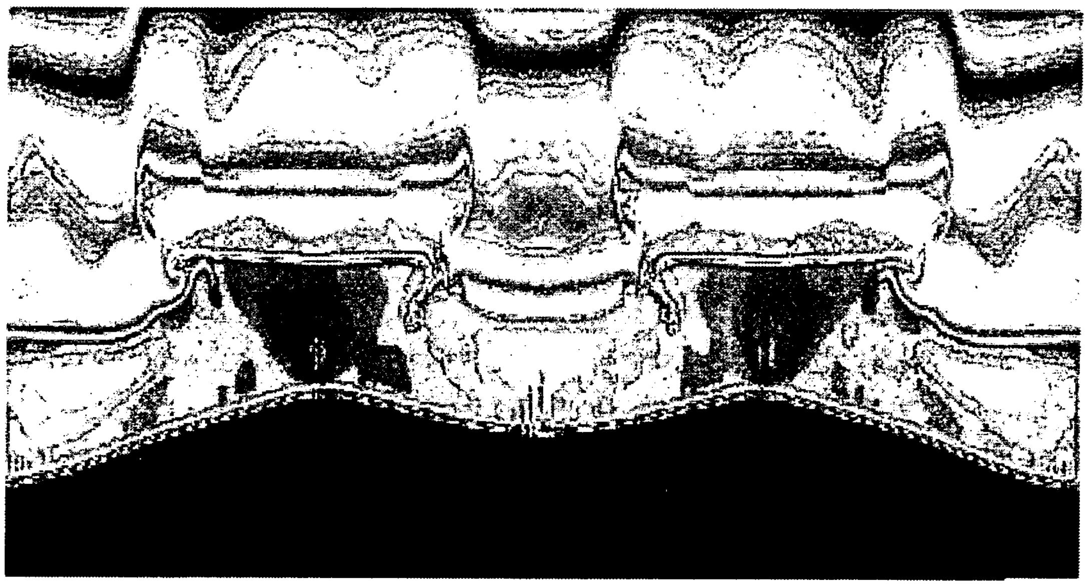
Preliminary LASNEX Calculations Predicted Closure of Gap at Late Times



# Schematic diagram and density contour of the Belly Band defect

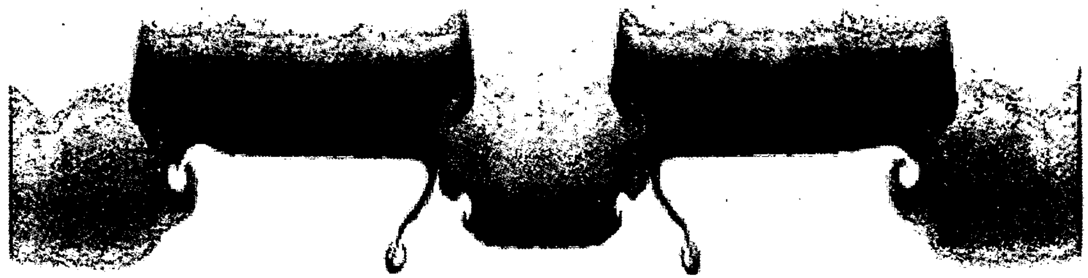



3.5 ns

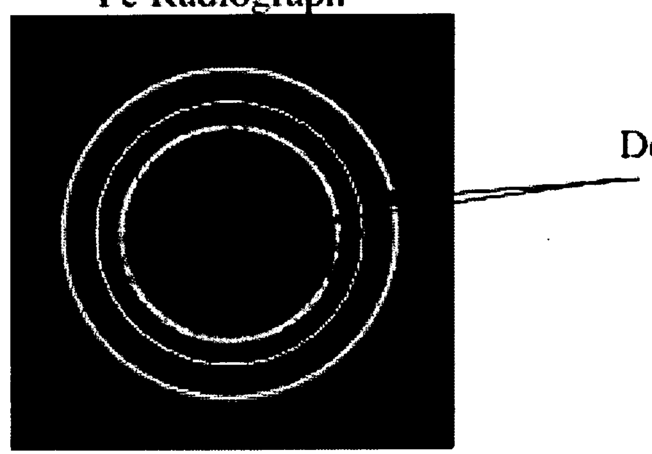


# Density contour and Fe radiograph of the Belly Band defect

5.1 ns



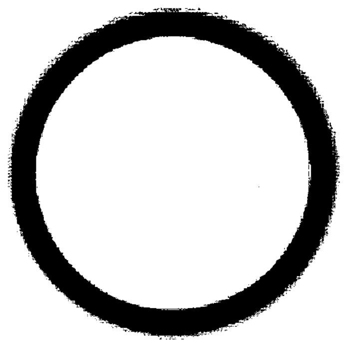
Fe Radiograph



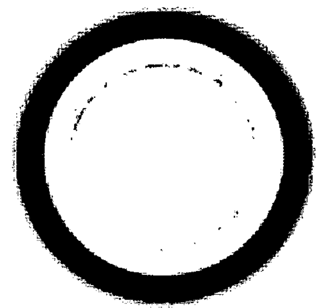
# Time evolution of the Belly Band defect as it collapses on axis

Radiographic images with an Fe backlighter

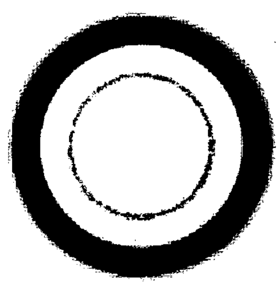
4.5 ns



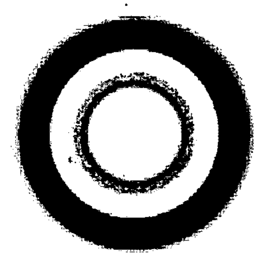
5.0 ns



5.5 ns

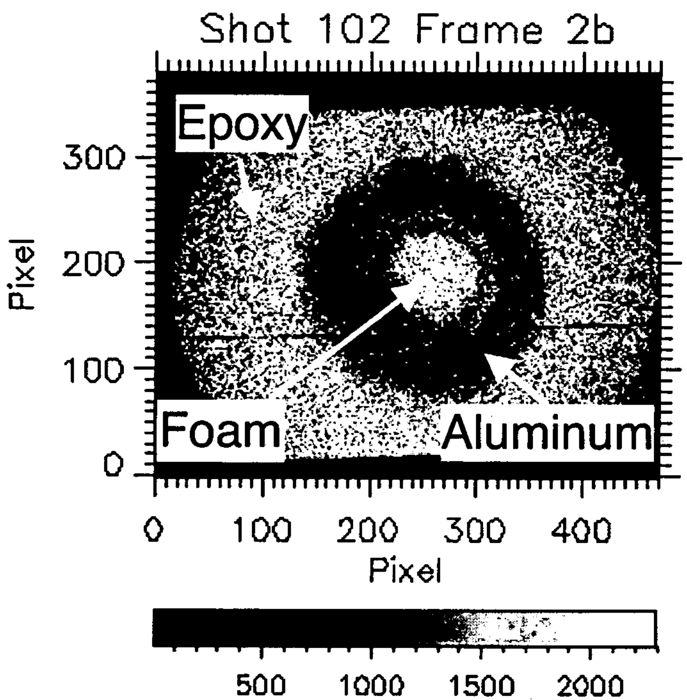


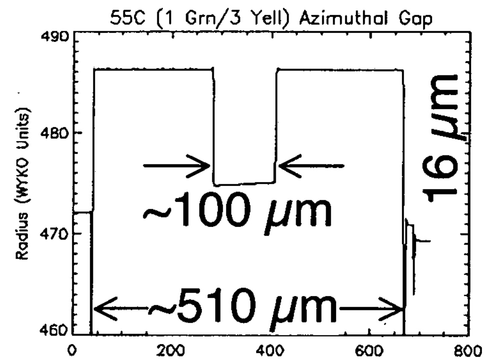
6.0 ns



# Differential Motion Between Marker Band and Azimuthal Defect is Clearly Visible.

Mass differential leads to different implosion velocities between Marker and Defect region.

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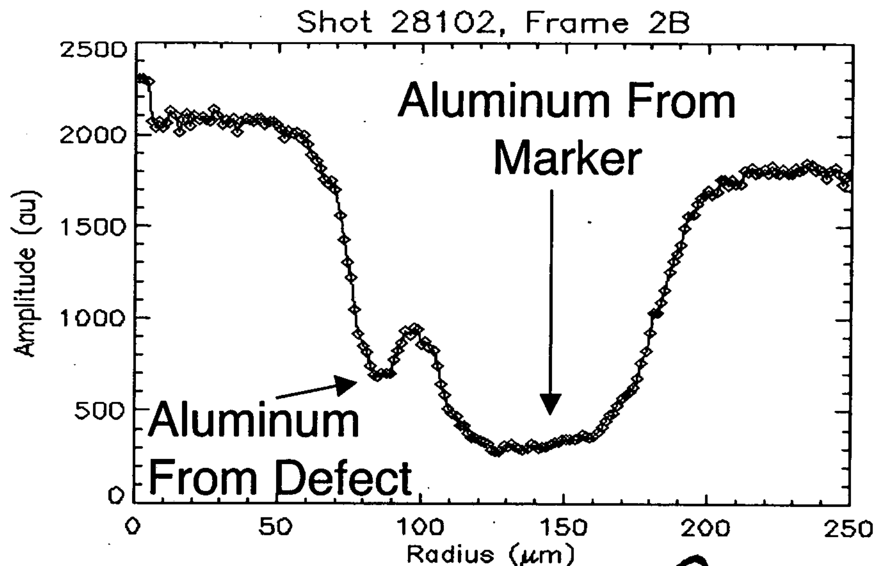


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# Future Directions

Study the evolution of defects without and than with surface roughness

Develop methods for increasing the mix width

Increase the effects of the Rayleigh-Taylor instability

Develop methods for studying mode coupling